CHE: W production at NLO and the polarized sea distributions

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Progress in High p_T Physics at RHIC
BNL, 17-19 March 2010

One (big) Purpose of spin program: obtain a full set of polarized pdfs

information about nucleon polarization

Requires measurement and analysis of several processes

sensitive to different combinations

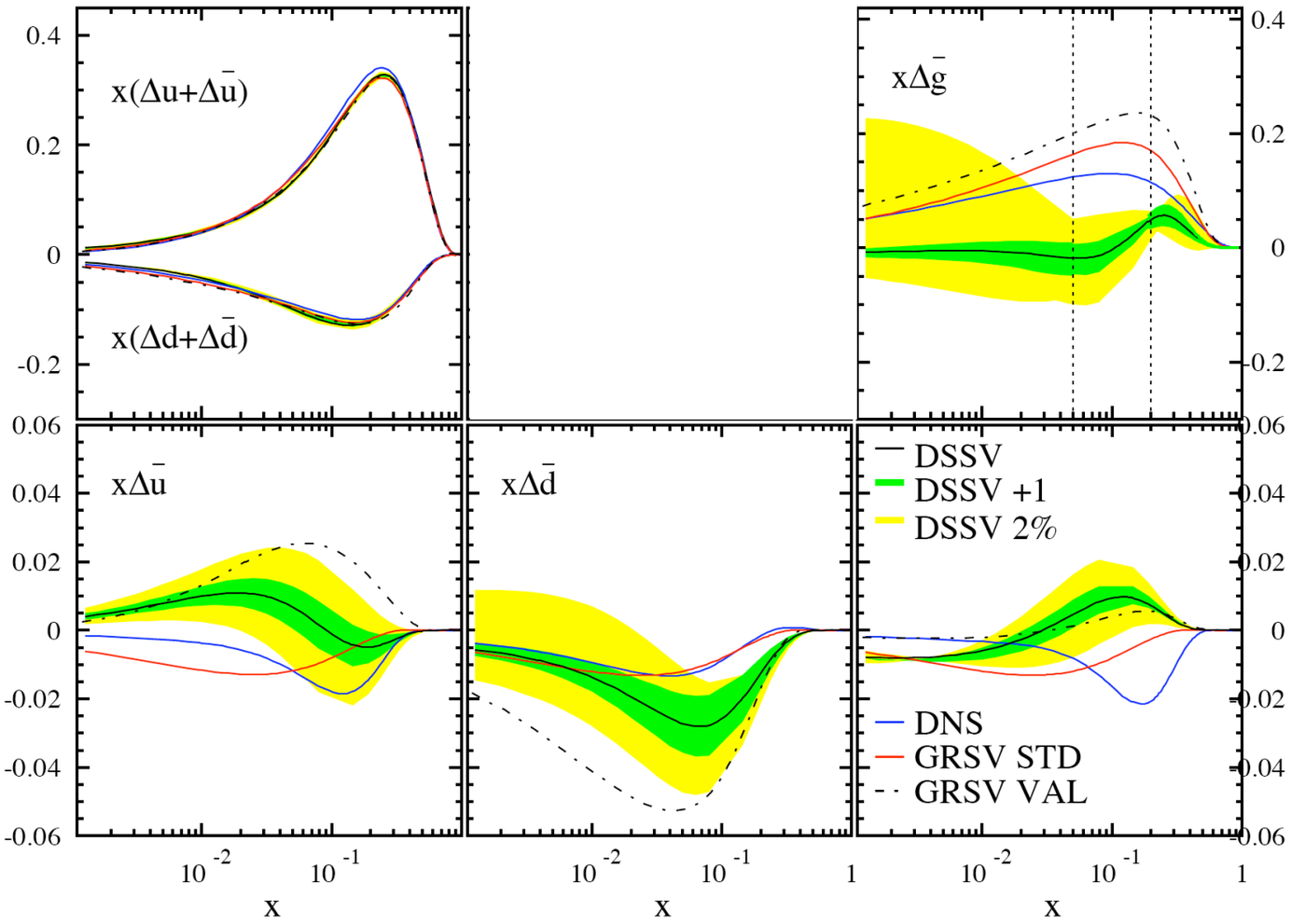
PDFs obtained as a result of a global fit

NLO : state of the art

DSSV analysis

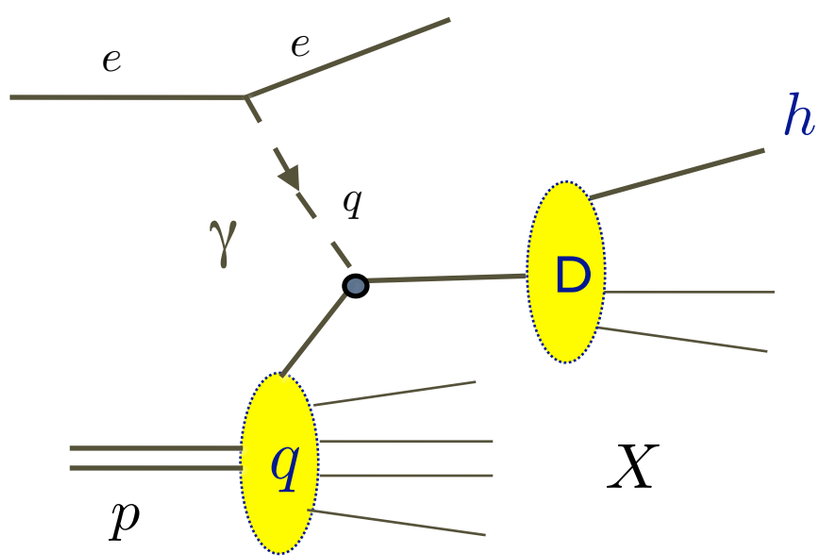
de F. , Sassot, Stratmann, Vogelsang

Not negligible uncertainty on antiquark polarized densities



All information comes from SIDIS ...

SIDIS



$$Q^2 = 10\ \mathrm{GeV}^2$$

q/qbar separation (fully) depends on fragmentation functions DSS

de F. , Sassot, Stratmann

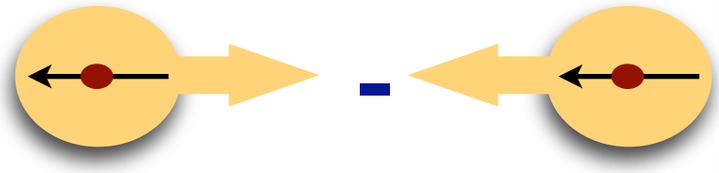
Difficult to quantify "uncertainties" from fragmentation

Need a cleaner observable for antiquark density measurement

W single-spin asymmetries

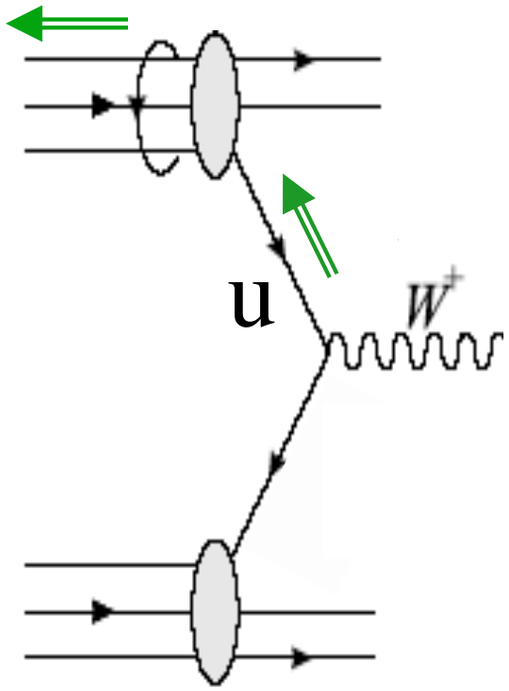
If parity violated can have $A_L = \dfrac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \neq 0$

- W couples only to one helicity type: max. parity violation



Only one polarized beam

Polarized



unpol.

$$\frac{\Delta q_i(x_1)\, q_j(x_2)}{q_i(x_1)\, q_j(x_2)}$$

~ DIS

- Large asymmetries possible
- W mass provides hard scale: pQCD

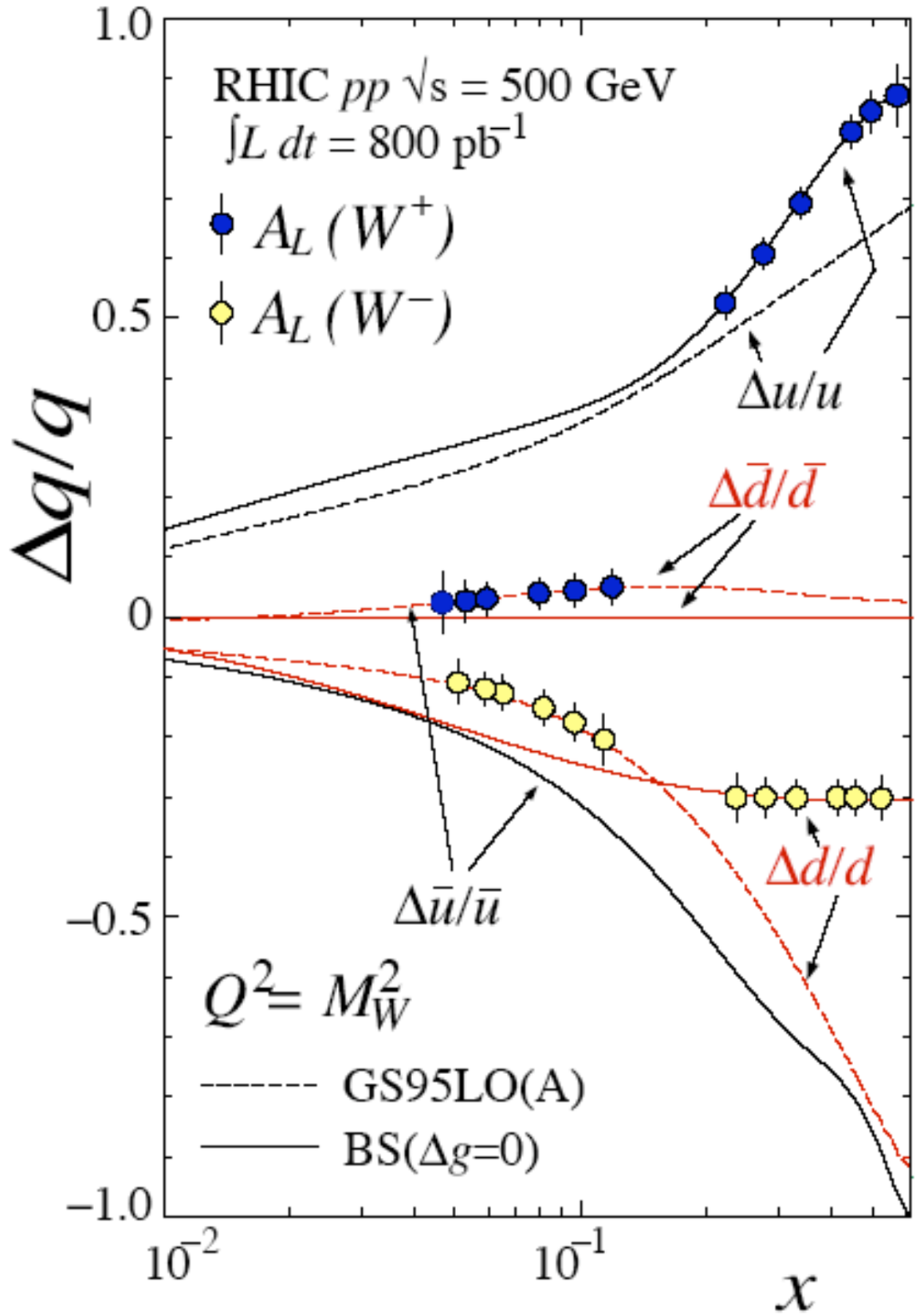
W single-spin asymmetries

Should have strong sensitivity on flavor structure

Bourrely, Soffer

$$A_L^{W^+} \approx -\frac{\Delta u(x_1)\,\bar{d}(x_2) - \Delta\bar{d}(x_1)\,u(x_2)}{u(x_1)\,\bar{d}(x_2) + \bar{d}(x_1)\,u(x_2)}$$

$$x_{1,2} = \frac{M_W}{\sqrt{S}} e^{\pm y_w}$$

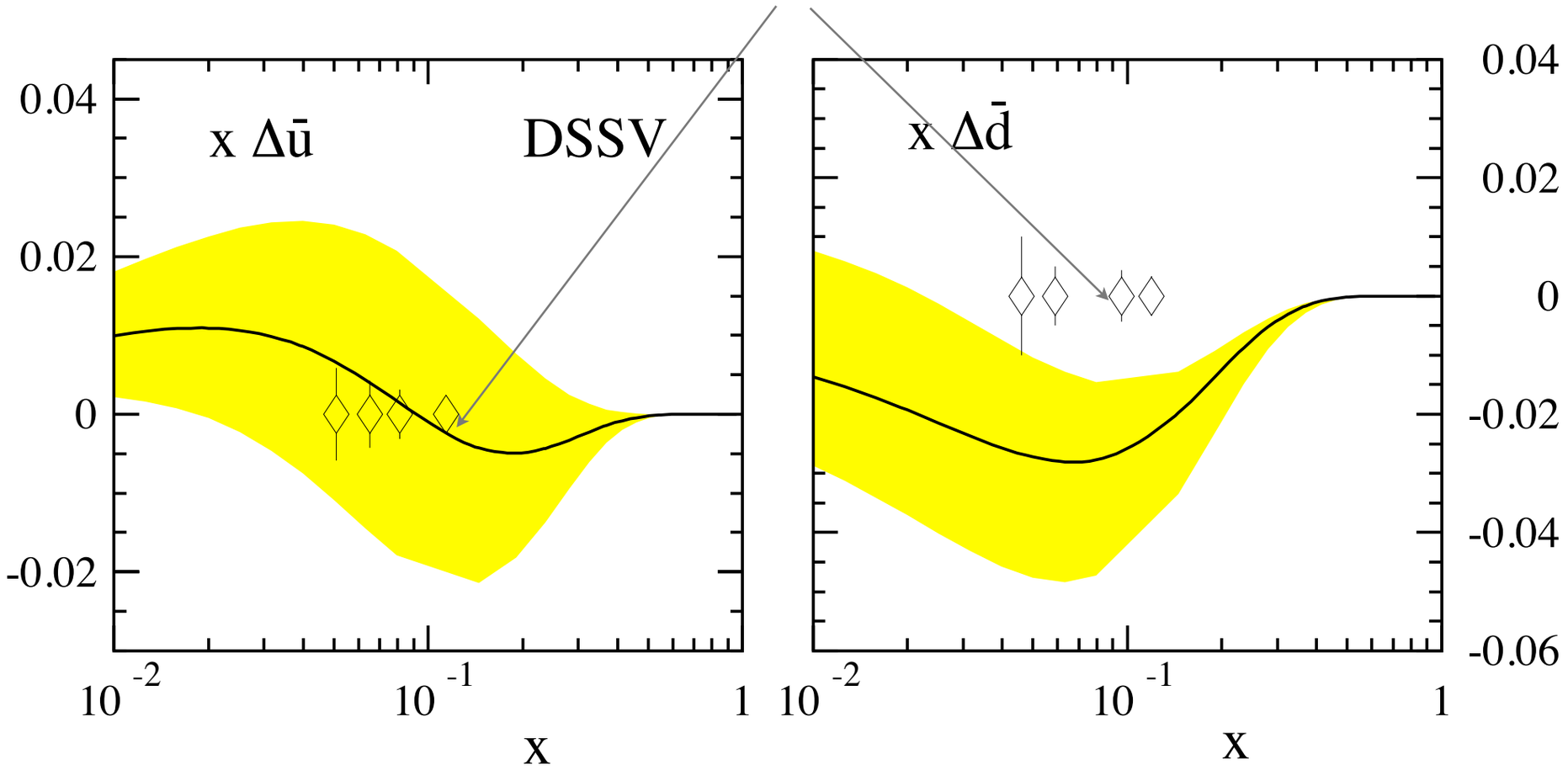


First* analysis anticipates good prospect

* Relies on W kinematics

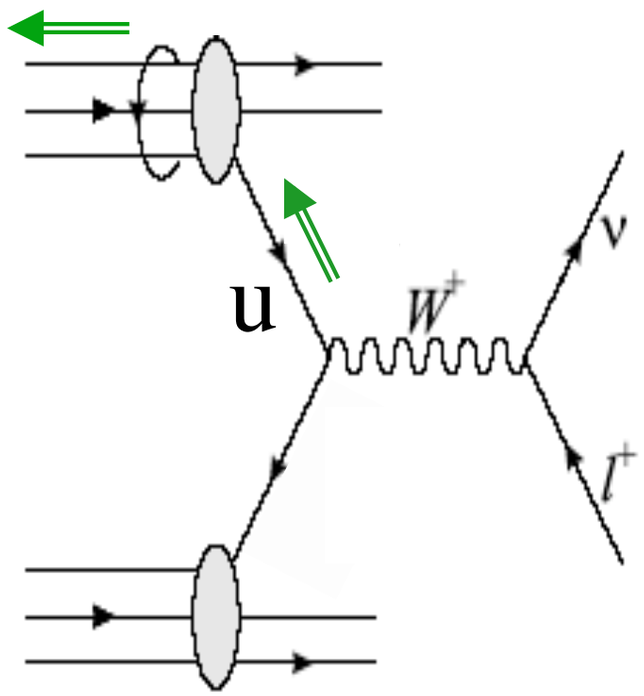
Lepton affects both kinematics and dynamics

Bourrelly Soffer estimate for 800 pb^{-1}



Will need reasonably high statistics to 'compete' with SIDIS

Move to next step : generate pseudodata for lepton ("W") asymmetries and study direct impact on global analysis



unpol.

NLO needed for quantitative studies in pp collisions ~ 30% effect for W production

Unpolarized NLO calculations available (exclusive): J.Campbell, K.Ellis

Monte Carlo for FeMtobarn processes

Even at NNLO! K.Melnikov, F. Petriello

S.Catani, L.Cieri, D.deF., G.Ferrera, M.Grazzini

plus NLO and NNLO analytical (inclusive)

None of them involve polarization

And there is also RhicBos P. Nadolsky, C.-P.Yuan

★ performs q_T resummation: very relevant for transverse momentum distribution of W but not needed (not convenient) for RHIC observables

★ 'NLO' implementation not reliable

★ Very hard to include in global analysis

Need to count with a new calculation $\sigma\left(pp \underset{W}{\rightarrow} e\bar{\nu}X\right)$

- Exclusive to implement experimental cuts
- Unpolarized, single polarized and double polarized
- "Ready/Available" for Mellin implementation
- Full NLO in line with other observables already in fit
- Allow to compute Z/Gamma 'background'

Monte-Carlo-like (set of) code(s)

CHE : Collisions at High Energies

Full access to final and initial state kinematics :
compute any infrared-safe observable

New channels at NLO

W-

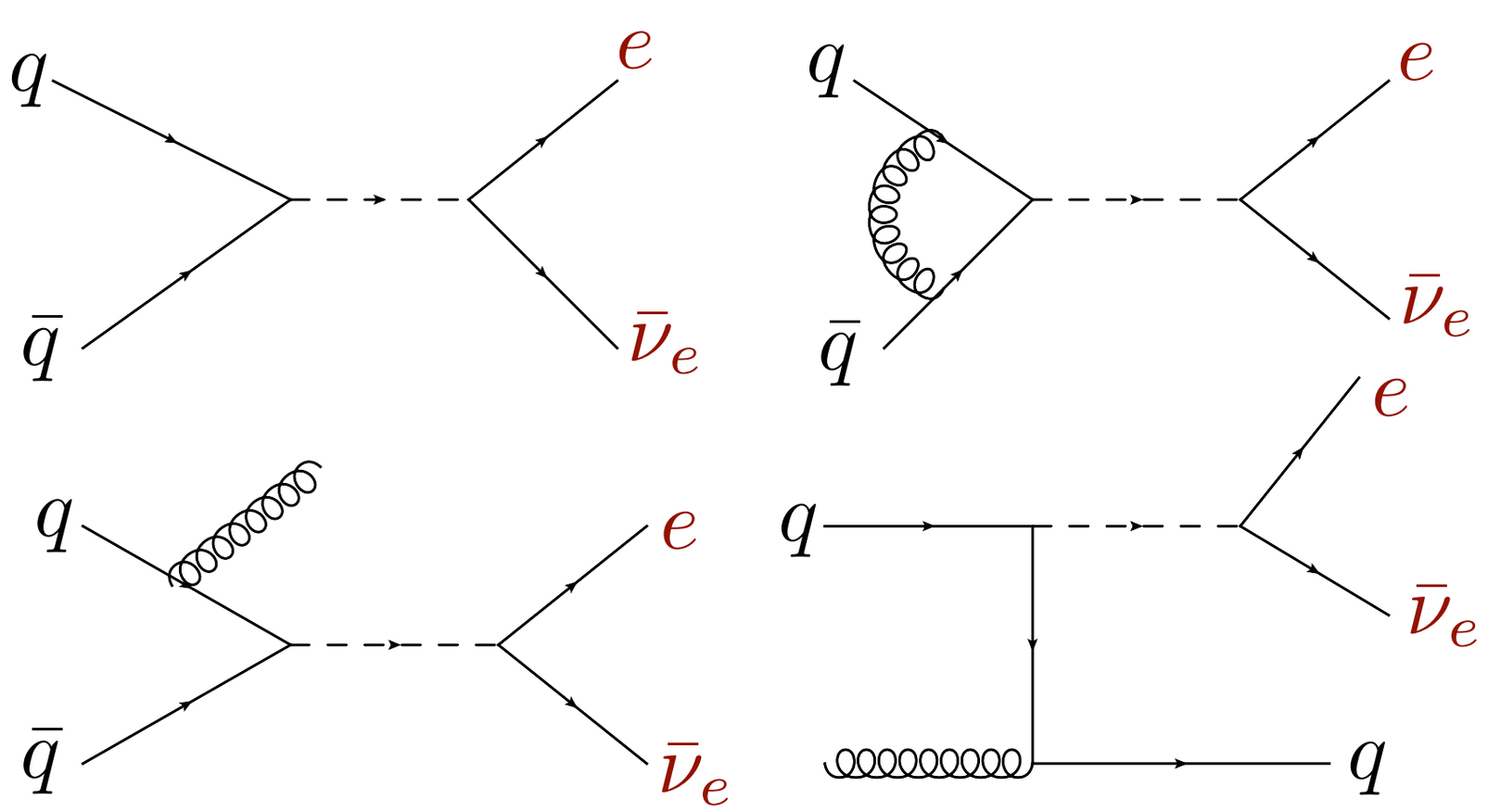
$$
\begin{aligned}
\Delta\bar{q}\; q &\to e\,\bar{\nu}_e \\
\Delta q\; \bar{q} &\to e\,\bar{\nu}_e \\
\Delta\bar{q}\; g &\to e\,\bar{\nu}_e\,\bar{q} \\
\Delta g\; \bar{q} &\to e\,\bar{\nu}_e\,\bar{q} \\
\Delta q\; g &\to e\,\bar{\nu}_e\,g \\
\Delta g\; q &\to e\,\bar{\nu}_e\,g
\end{aligned}
$$

Subtraction Method use

FKS: Frixione, Kunszt, Signer

all Checks OK!

Some diagrams ..



Rather simple to use

```
'test'                  ! prefix for files
 500.d0 1.d0            ! energy,  fact/renorm. scalefactor
  0                     ! polarization   0(unpol)  1(single pol)  2(double pol)
 -1                     ! Charge of the final state W
  1  1                  ! Hadron beams  p=1 pbar=-1
  46                    ! set of pdfs beam 1
  46                    ! set of pdfs beam 2 =1 if lpol=0 or 2
  -60    -60            ! Number of iterations for vegas (LO, NLO)
  2   2                 ! Vegas parameters: 0 to exclude, 1 for new run, 2 to restart
  250000  1500000       ! Number of calls for vegas
```

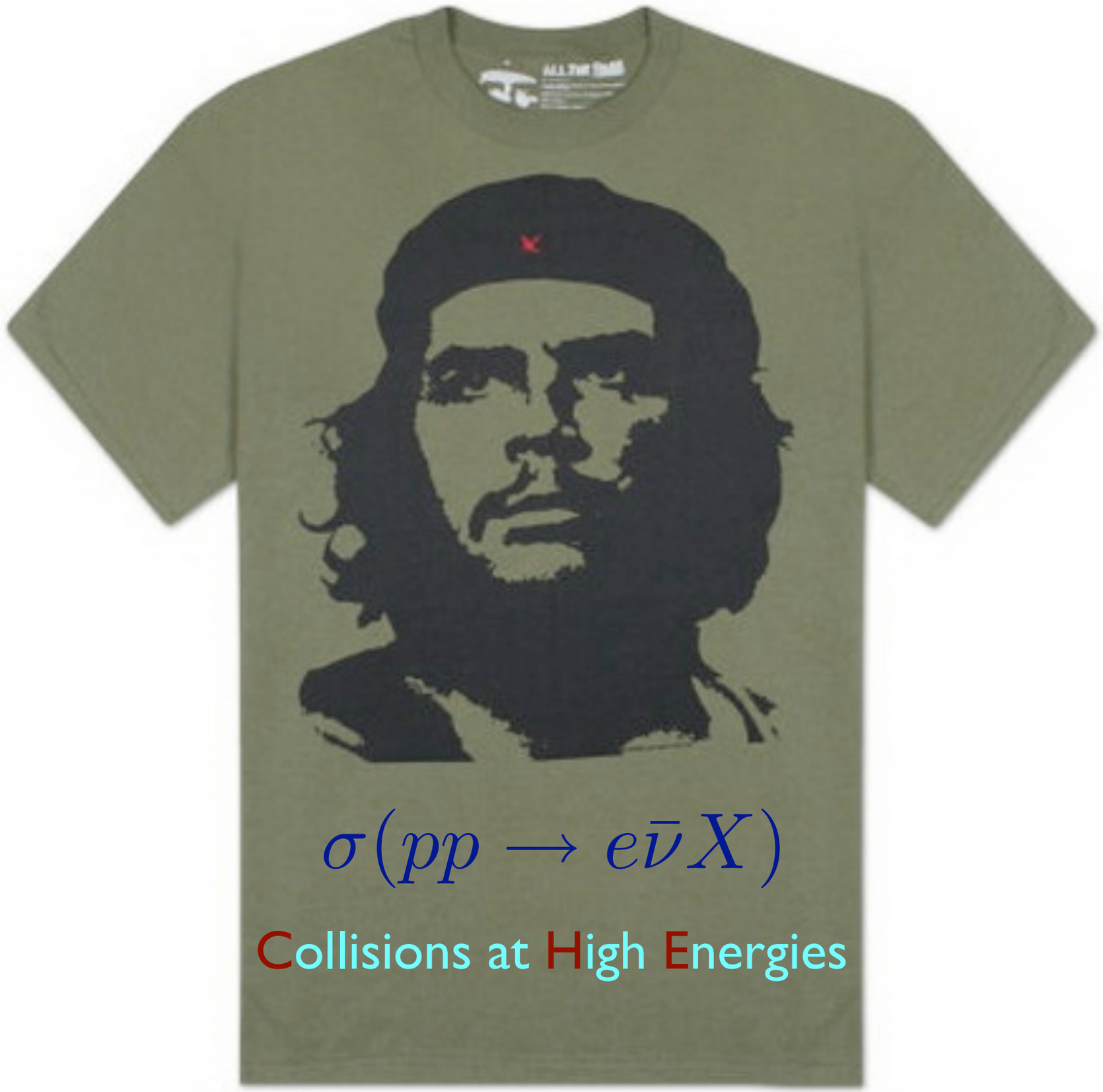
Can use different pdfs, scales, etc

Define observable (bin cross-section) in "user file" : output in topdrawer file

subroutine outfun(www)

```
c  This is the user analysis routine. It is called for each generated event with the parameter
www: weight of the event
c The kinematic of each particle is given by
c       xkt(i)=modulus of the transverse momentum of particle # i  in GeV
c       xeta(i)=pseudorapidity of particle # i
c      xphi(i)=azimuthal angle of particle # i
c      xkt(i),xeta(i),xphi(i) correspond to
c                                          i=1 jet
c                                          i=2 lepton
c                                          i=3 neutrino
c                                         (i=4 W boson as e+nu)
c
c The rapidity is POSITIVE in the direction of beam 1
c
c     To fill the histograms, use
c     topfill(hn,x,weight)
c where:
c      hn = histogram number
c      x = x value
c    weight = weight of the event
```

Available upon request



$$\sigma(pp \to e\bar{\nu}X)$$

Collisions at High Energies

single inclusive Electron/positron Asymmetries with CHE

- NLO
- Include Z/Gamma contribution (~7% for e^+ but ~44% for e^-)
- MRST2002 for unpolarized
- Various polarized pdfs (some already ruled out)

$$M_{e^+e^-} > 10\,\mathrm{GeV}$$

Z.Kang, J.Qiu, W.Vogelsang

$$\sqrt{S} = 500\,\mathrm{GeV}$$

$$\mu_F^2 = \mu_R^2 = \frac{M_W^2 + p_T^2}{2}$$

$$M_W = 80.398\,\mathrm{GeV}$$
$$M_Z = 91.876\,\mathrm{GeV}$$

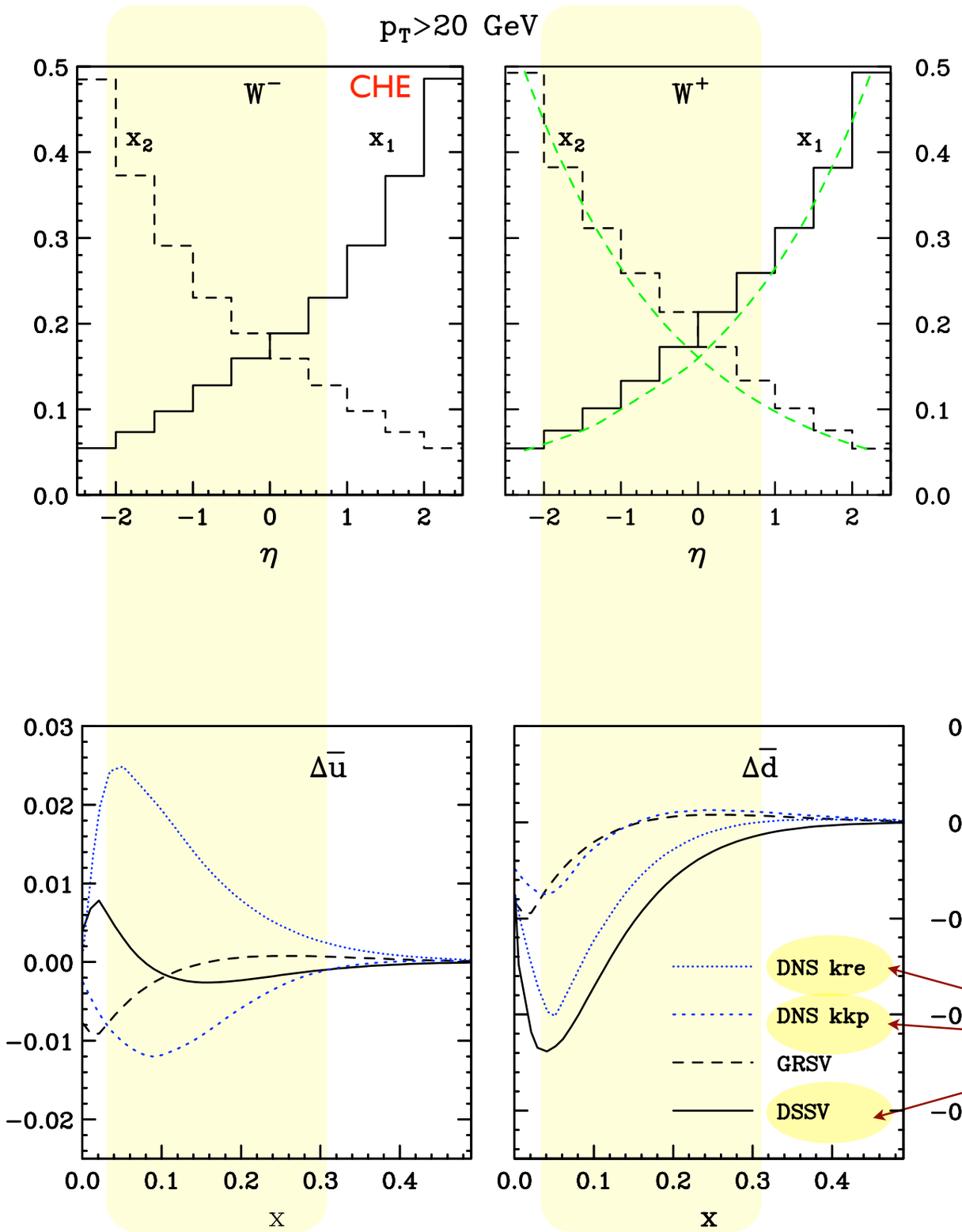
couplings from PDG

Concentrate on lepton rapidity distributions
(discussion about transverse momentum)

$$p_T^{\mathrm{lepton}} > 20\,\mathrm{GeV}$$

Lepton rapidity inherits relation to x

$$x_{1,2} = \frac{M_W}{\sqrt{S}} e^{\pm y_w}$$



1:polarized beam

$$\text{--------} < X_{1,2} > \simeq \frac{M_W}{\sqrt{S}} e^{[\pm \eta/2]}$$

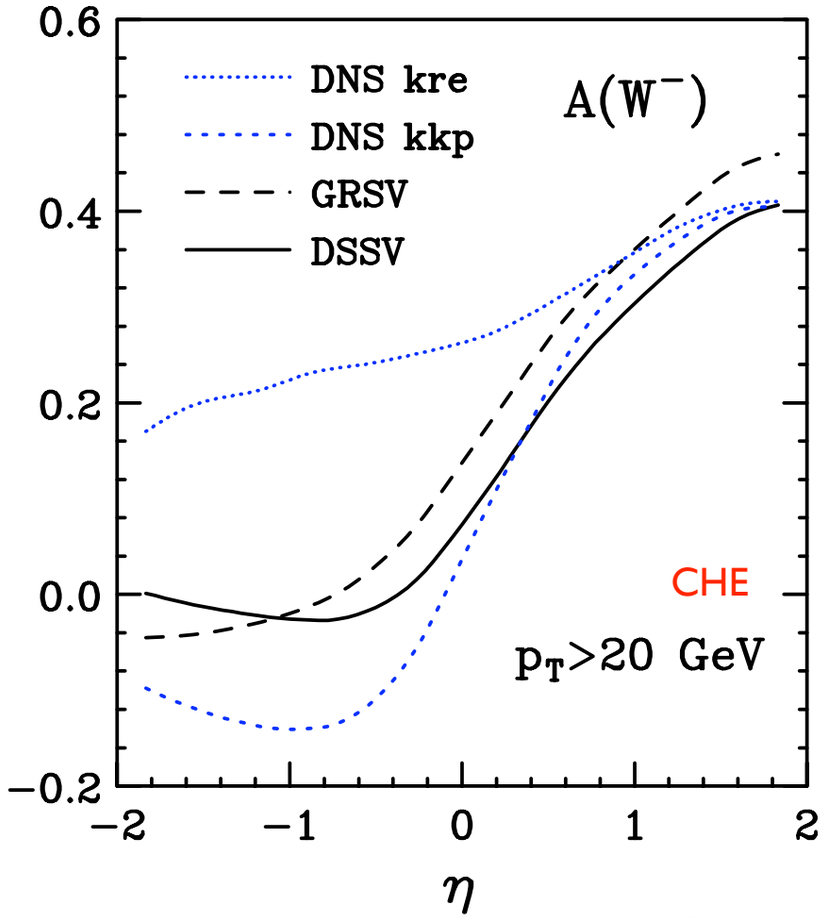
NWA

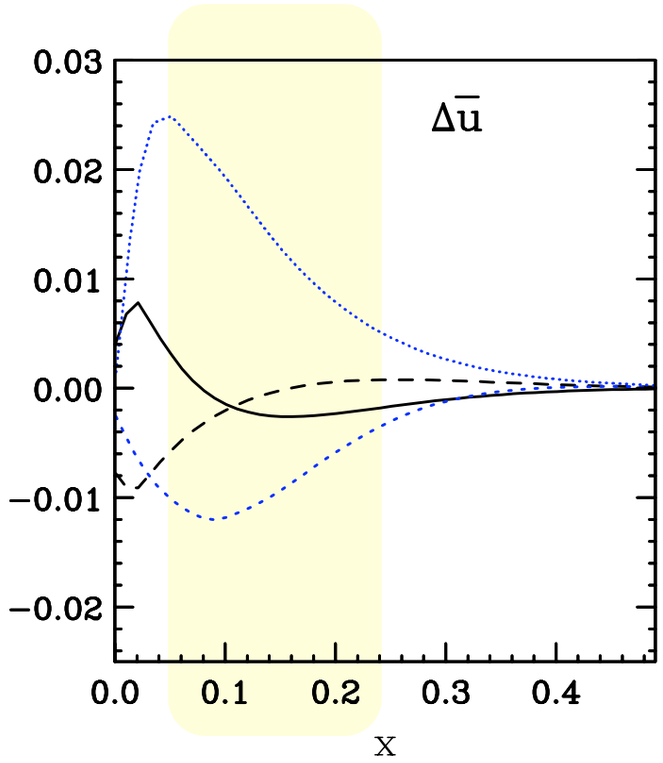
$$M_W \simeq 2E_T \cosh(y_W - y_l) \ , \qquad E_T \lesssim M_W/2$$

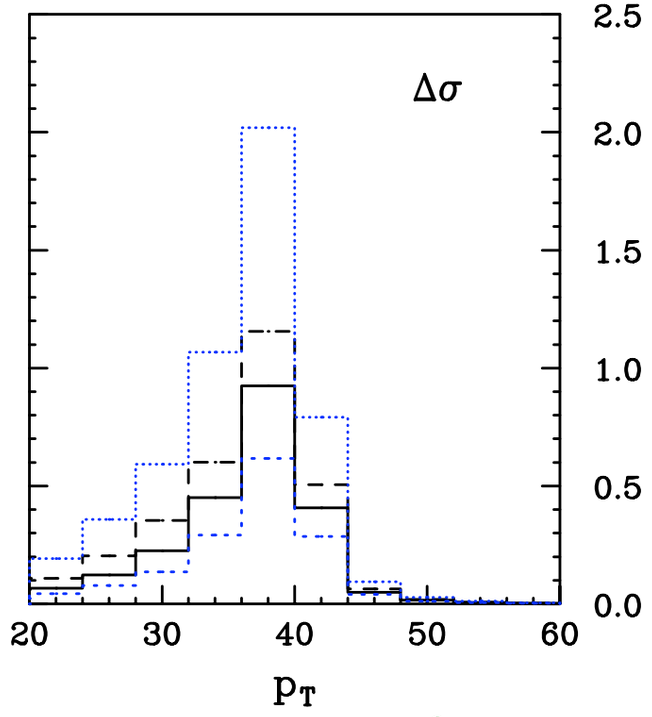
$$|y_W - y_l| \simeq \ln\left[\frac{M_W}{2E_T} + \sqrt{\left(\frac{M_W}{2E_T}\right)^2 - 1}\right]$$

include SIDIS with different FFs

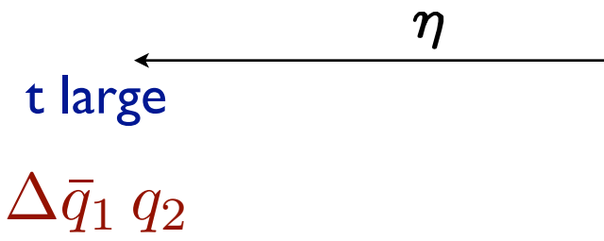
W- (electron rapidity)





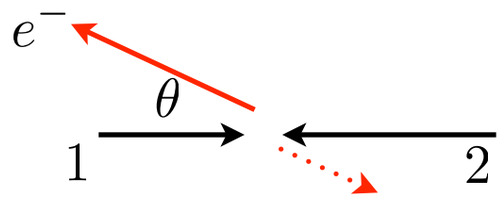


pT misses main features
(normalization but not shape and sign: W and QCD)



$\Delta\bar{q}_1\, q_2$ $\Delta q_1\, \bar{q}_2$

$$\Delta\bar{u}(x_1)d(x_2)(\hat{t}^2) + \Delta d(x_1)\bar{u}(x_2)(-\hat{u}^2)$$



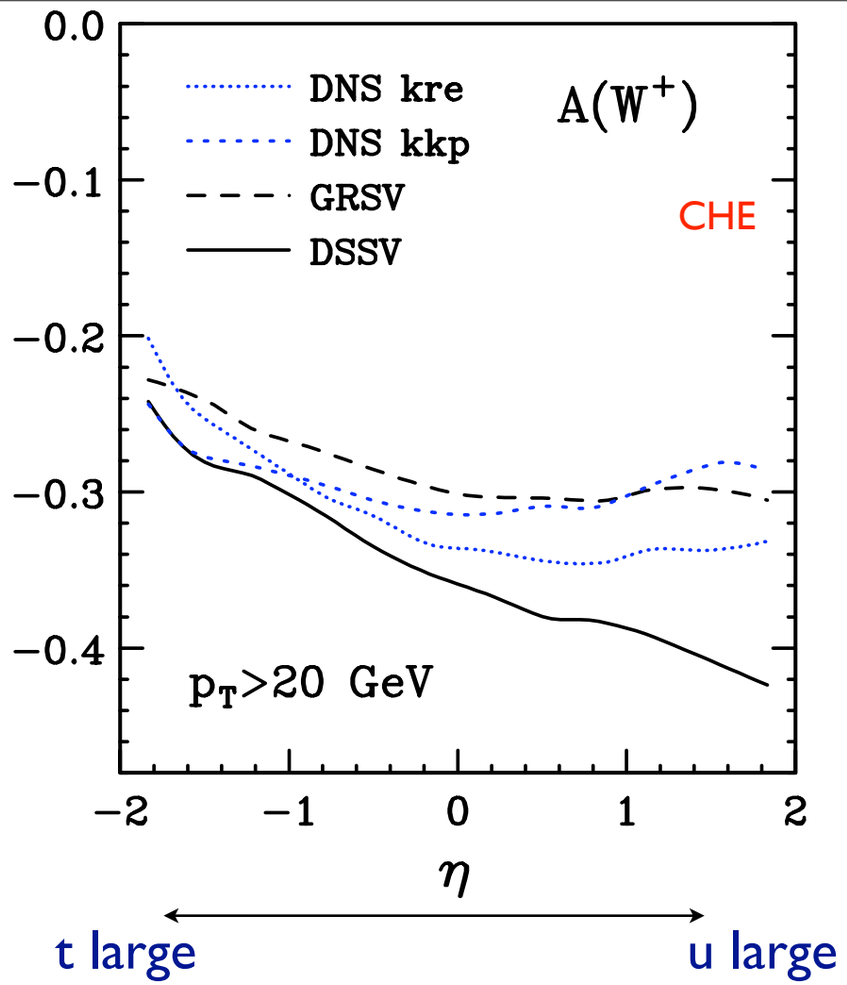
$$\hat{t}^2 \sim (1+\cos\theta)^2$$
$$\hat{u}^2 \sim (1-\cos\theta)^2$$

angular momentum conservation

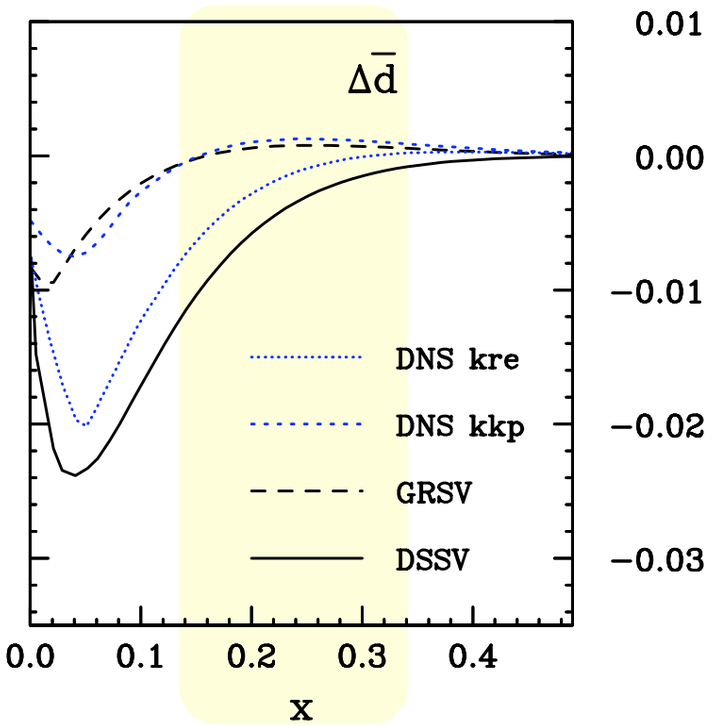
Best scenario: polarized antiquark contribution dominant at central/negative rapidity (small x)

Strong sensitivity on $\Delta\bar{u}$

W+ (positron rapidity)

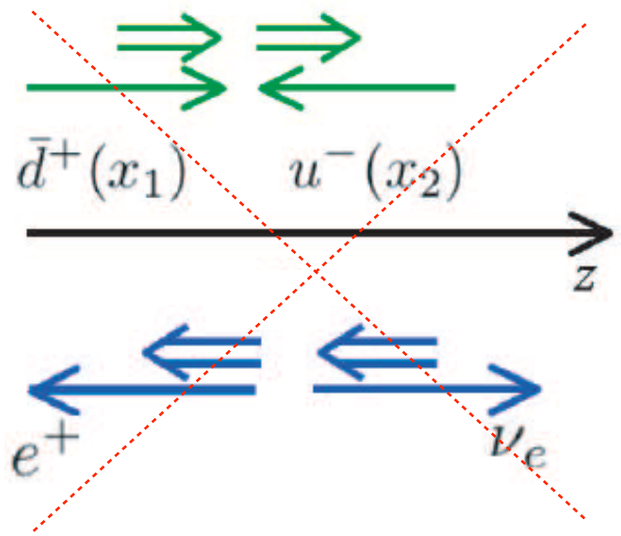


$\Delta q_1\, \bar{q}_2$ $\Delta \bar{q}_1\, q_2$



polarized antiquark contribution dominant at central/positive rapidity (larger x)

$$\Delta\bar{d}(x_1)u(x_2)(\hat{u}^2) + \Delta u(x_1)\bar{d}(x_2)(-\hat{t}^2)$$



Not that much sensitivity on $\Delta\bar{d}$ need to look at forward rapidities

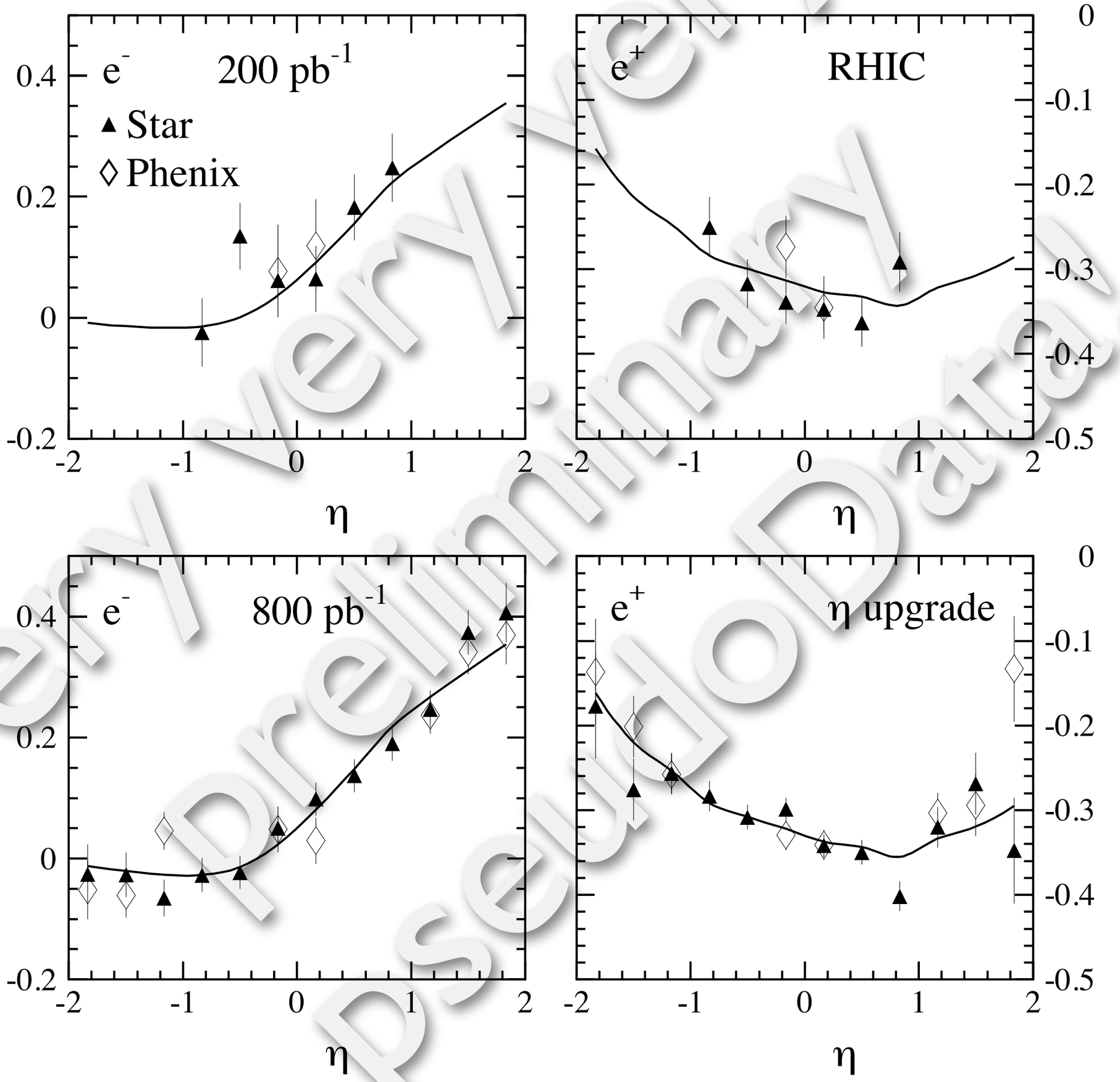
Data Simulation

pseudodata generated according to DSSV with gaussian dispersion with $\epsilon = \dfrac{1}{P\sqrt{\mathcal{L}\,\sigma}}$ $\qquad P = 60\%$

Different scenarios

Rapidity	STAR	'Phenix'
RHIC	$\lvert\eta\rvert < 1$	$\lvert\eta\rvert < 0.35$
RHIC 'extended'	$\lvert\eta\rvert < 2$	$1 < \lvert\eta\rvert < 2$ and $\lvert\eta\rvert < 0.35$

Luminosity
$\mathcal{L} = 200\,\mathrm{pb}^{-1}$
$\mathcal{L} = 800\,\mathrm{pb}^{-1}$



Include "data" in global fit and check impact on distributions

Global fit best in Mellin space : very fast solution of evolution equations and cross-sections (DIS,SIDIS)

$$f^n = \int dz\; z^{n-1}\, f(z)$$

$$d\Delta\sigma(pp \to l) = \frac{1}{2\pi i} \sum_{ab} \int_{\mathcal{C}_n} dn \;\; \Delta f_a^n \;\; \int dx_a \int dx_b\, x_a^{-n}\, f_b(x_b)\, d\Delta\sigma_{ab}$$

Standard Mellin Inverse

Contains all dependence on polarized pdfs

Completely independent on polarized pdfs : can be "pre-calculated" prior to fit

$$(d\Delta\sigma_{ab})_n = \int dx_a \int dx_b\, x_a^{-n}\, f_b(x_b)\, d\Delta\sigma_{ab}$$

still PS integrals
First time with a MC code!

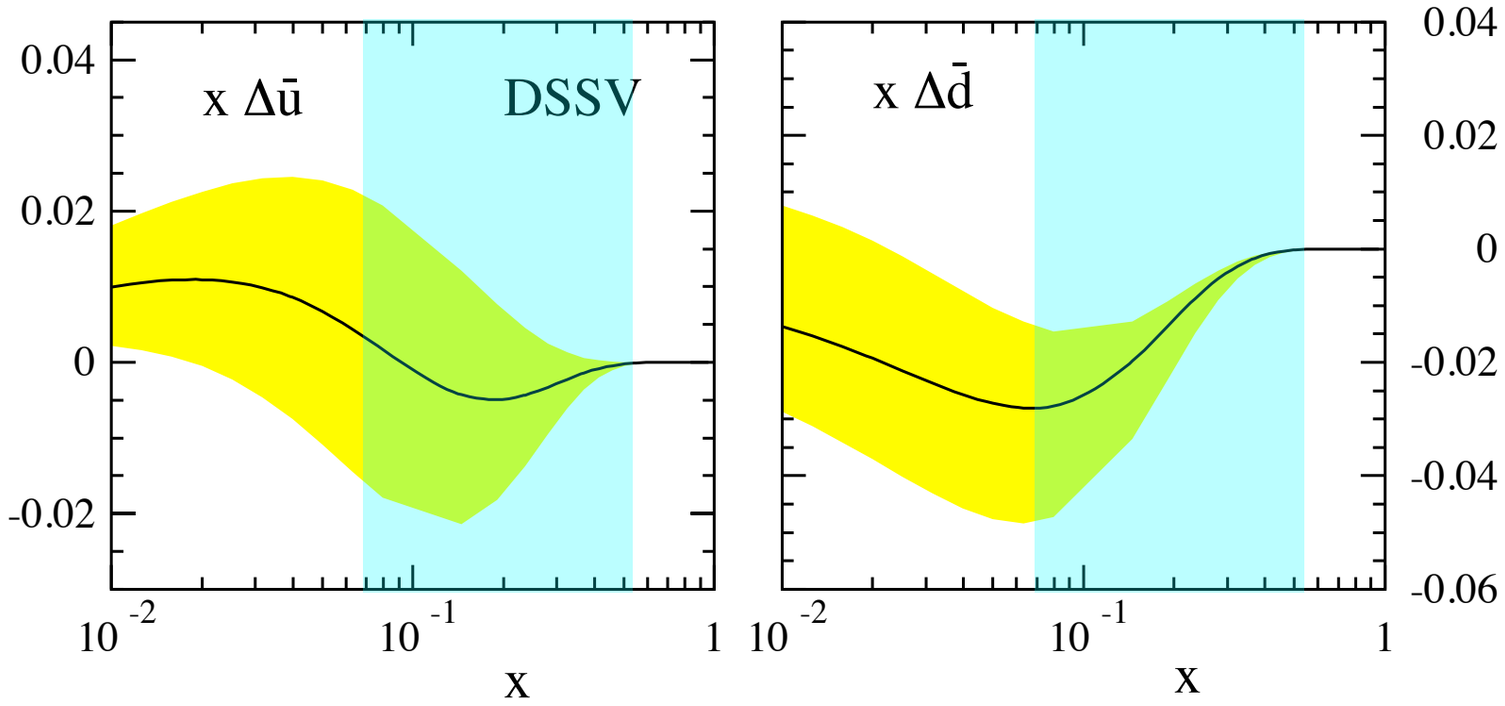
Use DSSV framework

Parametrization, Data, etc

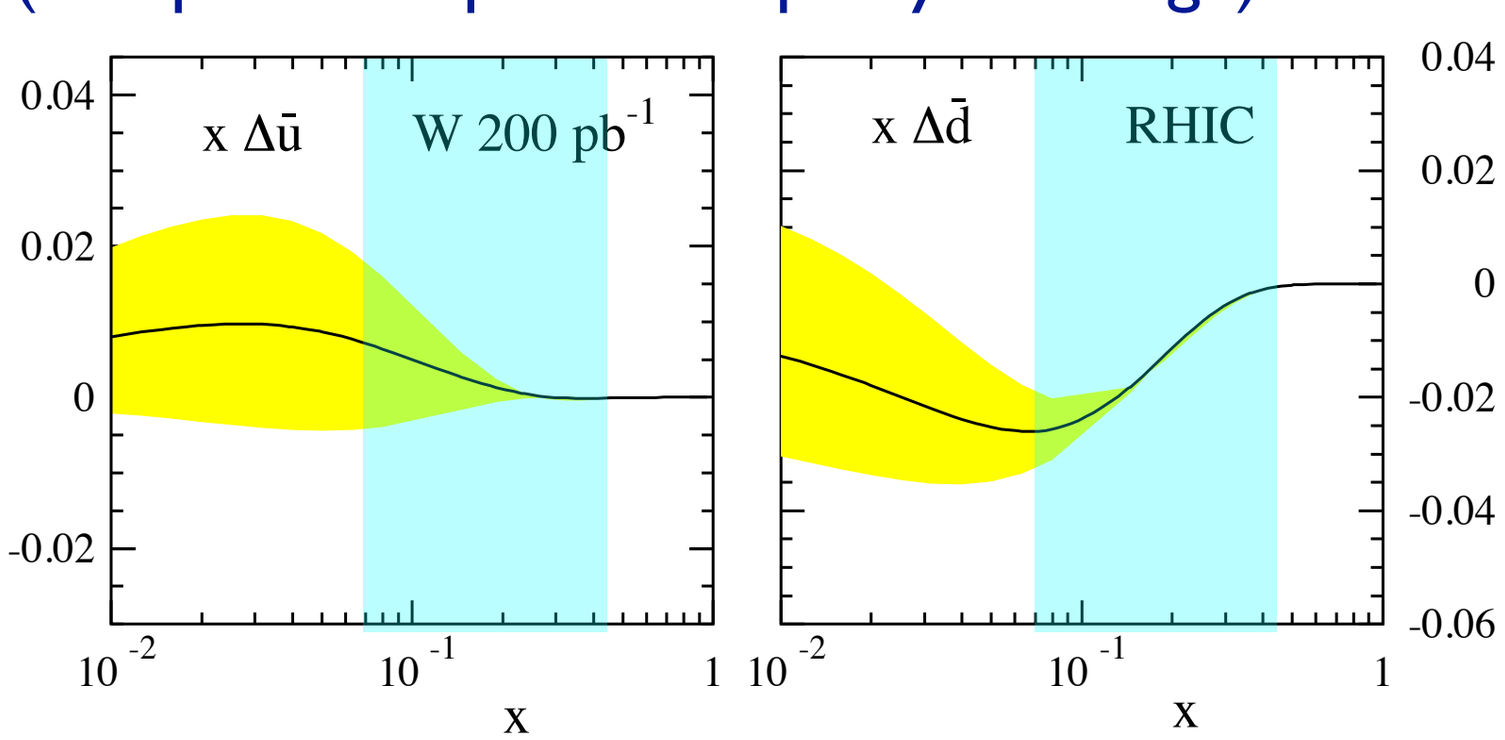
$$\Delta\chi^2 = 2\%\,\chi^2$$

$$\Delta f_j^{1,[0.001-1]}(Q^2) \equiv \int_{0.001}^{1} \Delta f_j(x, Q^2) dx$$

DSSV result

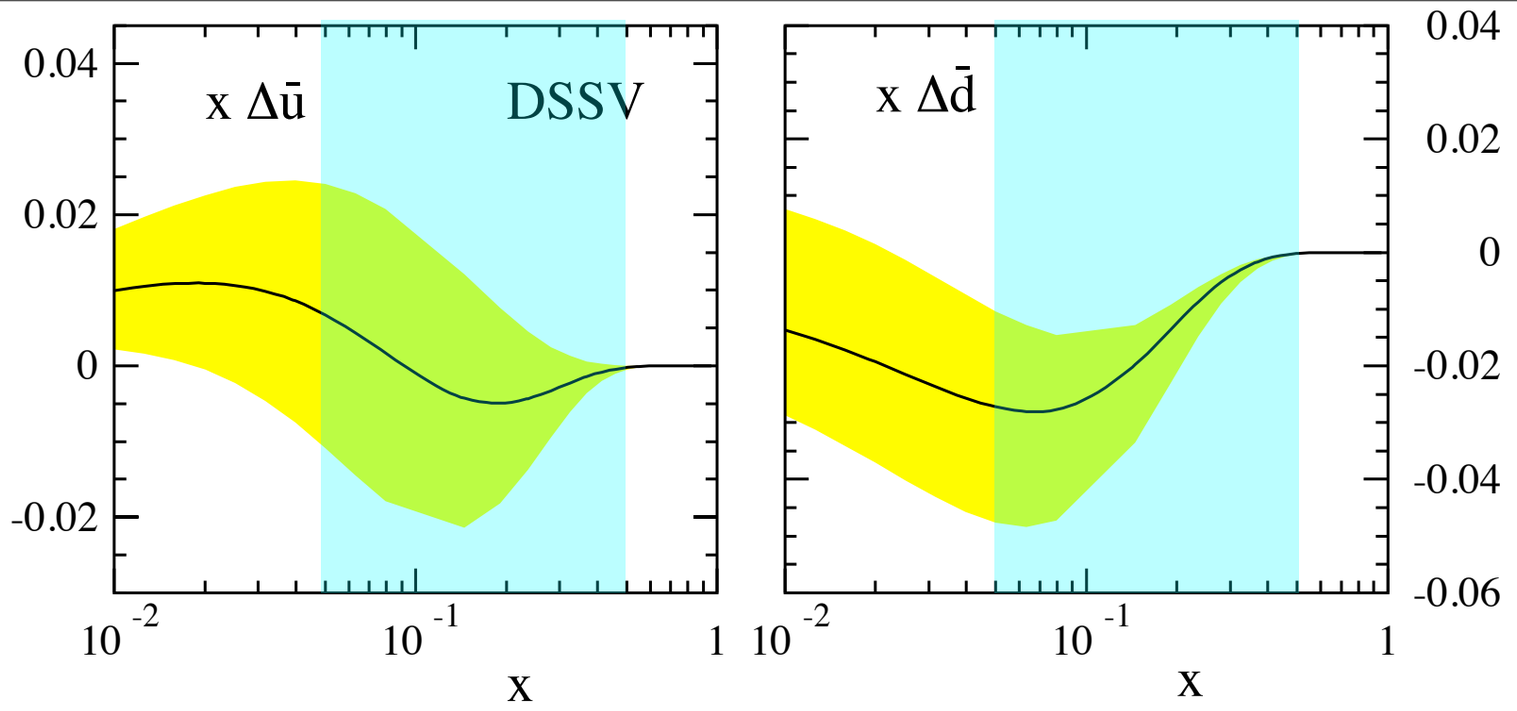


Include W data (200 pb^{-1} with present rapidity coverage)

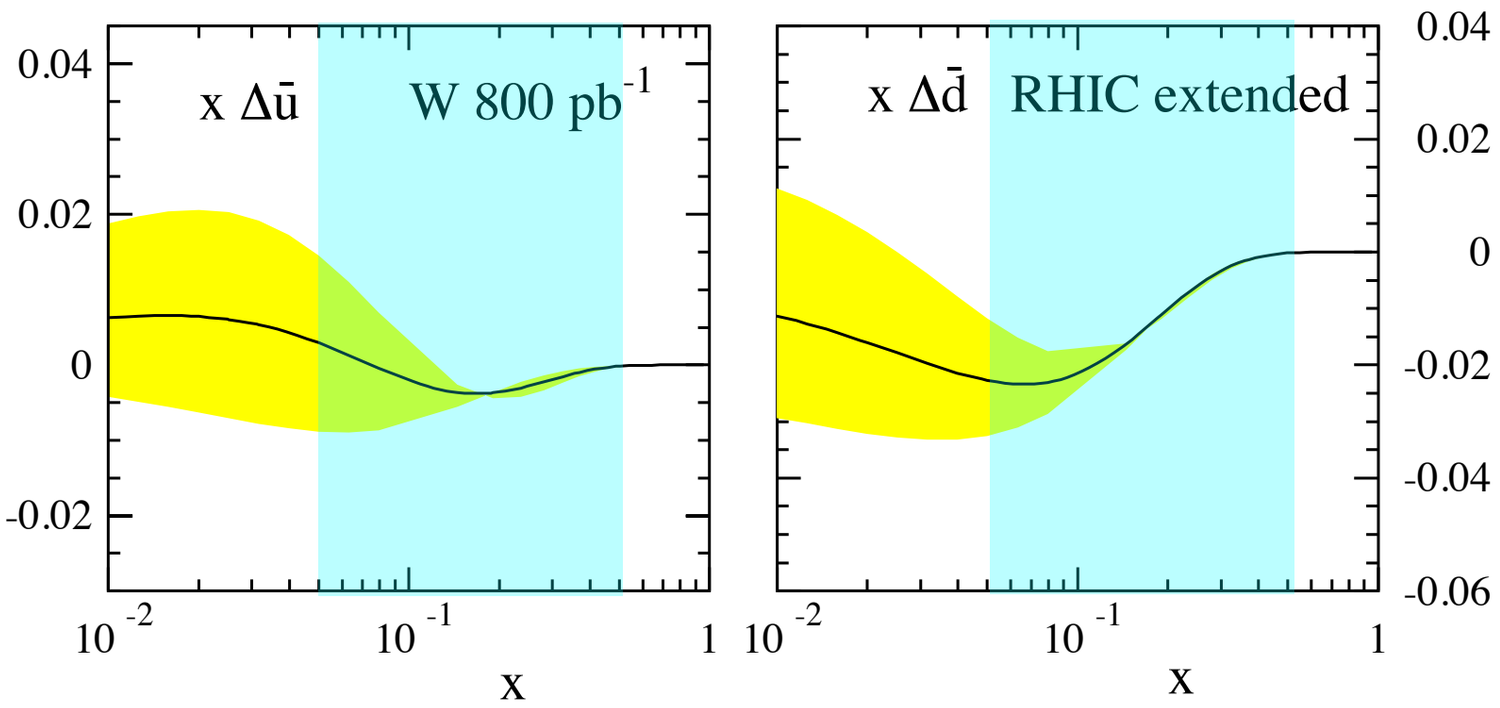


Little modification in the distributions

✓ Strong reduction in uncertainty band at $x > 0.07$!!



More precise data and extended coverage

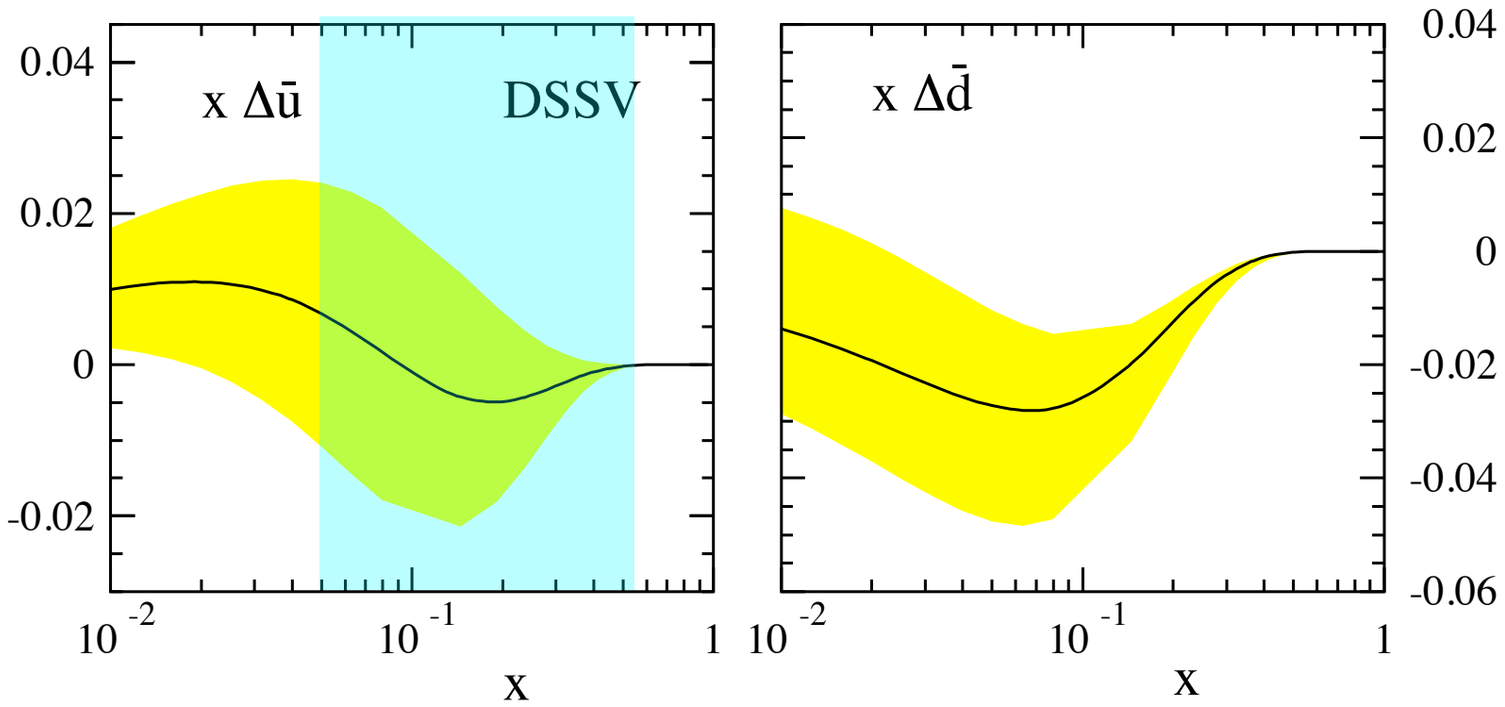


Very nice prospects for $x \gtrsim 0.05$

Simulated data generated in agreement with DSSV : strong bias towards SIDIS

What if SIDIS and W do not agree ? (as it usually happens with REAL data)

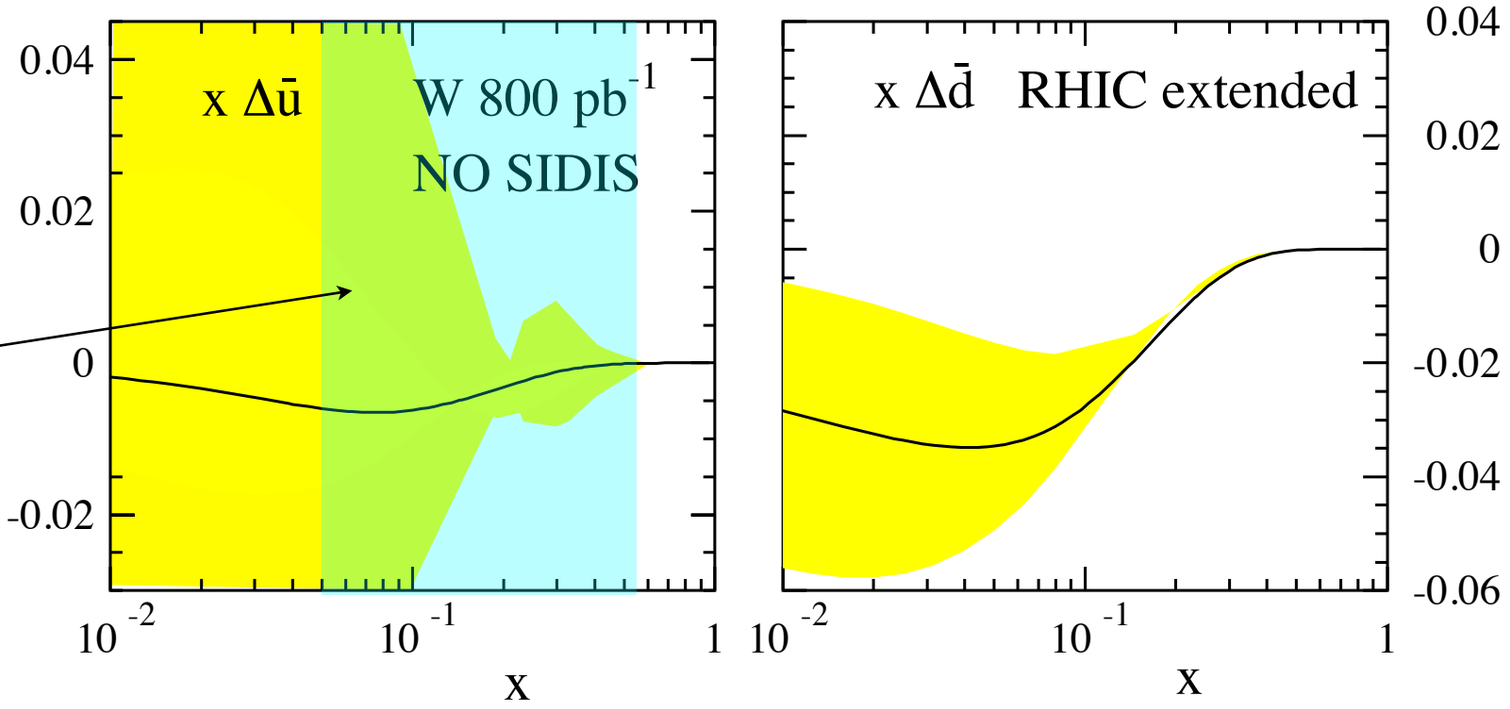
DSSV result (no W)



What W's can do alone (remove SIDIS)

Eliminate bias from SIDIS

RHIC with 200 pb^{-1}
more data needed



pretty good at x>0.05 but lack of resolution at smaller x

Summary (good news)

single inclusive lepton

✓ CHE : Full NLO calculation for ~~W~~ asymmetries

✓ Includes Z/Gamma contribution

✓ Can be included in Global Fit (Mellin grids)

✓ First (realistic) analysis with 'simulated' data

✓ W asymmetries clearly help to constrain $\Delta\bar{u}$, $\Delta\bar{d}$

$$x \gtrsim 0.05$$

During next decade : Confront/Compete/Check/Replace
SIDIS ! (in some kinematical range)